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SELECTING RECONNAISSANCE STRATEGIES FOR FLOODPLAIN SURVEYS

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SELECTING RECONNAISSANCE STRATEGIES

FOR FLOODPLAIN SURVEYS

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ABSTRACT

Multispectral aircraft and satellite data over the West Branch of the Susquehanna River were analyzed to evaluate potential contributions of remote sensing to floodplain surveys. Multispectral digital classifications of land cover features indicative of floodplain areas were used by interpreters to locate various floodprone area boundaries. The digital approach permitted Landsat results to be displayed at 1:24,000 scale and aircraft results at even larger scales. Results indicate that remote sensing techniques can delineate floodprone areas more easily in agricultural and limited development areas as opposed to areas covered by a heavy forest canopy. At this time it appears that the remote sensing data would be best used as a form of preliminary planning information or as an internal check on previous or ongoing floodplain studies. In addition, the remote sensing techniques can assist in effectively monitoring floodplain activities after a community enters into the National Flood Insurance Program. (KEY TERMS: remote sensing; floodplain surveys; multispectral digital classification; planning information).

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SELECTING RECONNAISSANCE STRATEGIES FOR FLOODPLAIN SURVEYS

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INTRODUCTION

The concept of using the capabilities of remote sensing to assist in the management of floodplains has an understandable appeal because of the inherent complexity of conventional survey methods and the need to monitor conditions over extensive floodplain areas. Before 1972, aircraft remote sensor capabilities had been considered and generated some interest in the floodplain management community. This interest in remote sensing was further spurred in 1972 by the launch of the Earth Resources Technology Satellite, now referred to as Landsat. This satellite provided a capability previously unavailable, namely, constant altitude and stability, and reduced sun angle variability, while recording multispectral variations on a repetitive basis.

Coupled with this idea of somehow delineating a narrow floodplain boundary from afar (from a few kilometers altitude with aircraft to over 900 kilometers with Landsat) was the existing knowledge that historical, geomorphological, and

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botanical indicators associated with the boundary between floodprone and non floodprone areas could conceivably be recognized using remote sensing techniques. Further justification for investigating this potential grew out of the aftermath of the 1972 Hurricane Agnes floods in the eastern United States where several billions of dollars in damage occurred in floodplain areas. Emphasis on improving the National Flood Insurance Program resulted, and the Flood Disaster Prevention Act of 1973 was instrumental in making an increased number of communities eligible for flood insurance protection. With this increased participation the need for and backlog of floodplain surveys rose dramatically.

The purpose of this paper is to evaluate the current capabilities of remote sensing for floodplain management and to report on a specific case study regarding the feasibility of utilizing remotely sensed multispectral data to delineate floodplains. Because the 80 m resolution of Landsat is not entirely optimum for floodplain applications, higher resolution aircraft data were investigated in parallel in the case study which was a cooperative effort by the U.S. Army Corps of Engineers (USACE), the National Aeronautics and Space Administration (NASA), and the Pennsylvania State University.

Floodplain Mapping Requirements & Responsibilities

The importance of floodplain maps has increased drastically since the passage of the National Flood Insurance Act of 1968 which defined qualification requirements for Federally subsidized flood insurance. This act required that a ratemaking study based on detailed hydrologic analysis be undertaken for each community before it could become eligible to purchase flood insurance. Because this requirement resulted in a delay in the provision of insurance, an Emergency Flood Insurance Program was enacted in 1969 allowing insurance to be sold before an actuarial study was conducted for a community as long as the community had applied for eligibility and agreed to adopt certain land use measures to reduce future flood losses.

The Federal Insurance Administration (FIA) of the U.S. Department of Housing and Urban Development (HUD) implements and administers the National Flood Insurance Program. This Program operates through an insurance industry pool under the auspices of the National Flood Insurers Association (NFIA). FIA identifies local jurisdictions that are floodprone and therefore eligible for participation in the National Flood Insurance Program. The eligible areas are determined from flood hazard boundary maps compiled for FIA by other Federal agencies such as the USACE, U.S. Geological Survey (USGS), U.S. Soil Conservation Service (SCS), National Oceanic and Atmospheric Administration, Tennessee Valley Authority, and the U.S. Bureau of Reclamation, or private contractors.

The basis for the National Flood Insurance Program contains a number of primary features. First, an agreement between HUD and a community, whether it be a municipality or a county, must be reached on the apparent limits of the floodprone areas and required land use and regulatory measures for development in the floodprone areas. Second, the community may then apply to members of the NFIA for flood insurance as prescribed by FIA. Third, FIA will then develop and provide to the community actuarial rates for property in the floodprone areas. The community is given six months to adopt the 100-year flood standard in its local zoning and building code ordinances. Fourth, the basic HUD/community agreement must be maintained and a form of enforcing this agreement decided upon.

The key to the HUD and community agreement is the compilation of flood hazard and insurance rate maps, usually accomplished through an engineering study using hydrologic and hydraulic data. This engineering approach to mapping floodprone areas is followed by agencies preparing flood hazard maps that meet FIA specifications. This procedure includes the following:

1. Conduct a search for information about past floods, including location and elevation of high water marks.

2. Determine runoff volumes through relatively simple techniques; perhaps the unit hydrograph approach or runoff modeling based on watershed characteristics. This would include the various return period floods of 10, 50, 100, and 500 year frequency - the latter being the largest flood which is considered for land use planning.

3. Sum up all subwatershed flows to get runoff at basin outlet.

4. Route runoff downstream to desired points where the flood hazard area is to be determined. Ground surveys should be conducted at these points to obtain existing stream cross sectional profiles.

5. Calculate the flood water profile at each cross section from the runoff volume and the channel characteristics.

6. Plot the water surface on the cross section to determine where the water intersects the land.

7. Translate cross section data to a base map at the desired scale. Extrapolate surface water extent up-and downstream from cross section on the basis of topography and stream geometry. From the profiles and topography shown on the maps, depths can be determined.

The base map which is used to illustrate the location of the flood hazard boundaries must be of sufficient scale and clarity to permit the ready identification of individual building sites as either within or outside the area having special flood hazard. The community supplied base map should meet the following standards if possible: for municipalities, between 1:4,800 and 1:12,000 scale; and for counties, between 1:24,000 and 1:63,360 scale.

When these flood hazard boundary maps are available to communities, flood insurance under the emergency flood insurance program can be purchased. Flood insurance rate maps are prepared after a ratemaking study of the community has been completed and actuarial rates have been established. This map indicates the actuarial rate zones applicable to the community at a scale similar to the flood hazard boundary map. The flood insurance rate map delineates the area in which flood insurance may be sold under the regular flood insurance program.

In 1968, when the flood insurance program was started, USACE estimated that 5,000 communities were identified as floodprone. By May 1973 FIA had increased that estimate to 10,000 communities, 13,600 by December 1973, and 16,300 by June 1974. A year later in June of 1975 the total identified floodprone communities had risen to 21,411 with little potential for further increase (Comptroller General of the United States, 1976). The result of this rapid increase in communities requiring surveys has been a staggering increase in associated costs. In fiscal year 1977 FIA will spend close to $75 million on the mapping program with $45 million apportioned for private contractors and $30 million for cooperating Federal agencies. The USACE will receive $15 million from FIA and will spend about $3 million additional for their own studies (G. Phippen, personal communication, 1976). It is expected that the entire mapping program, when completed, will exceed $1 billion. The costs for a flood insurance study currently average from $750 to $3,000 per stream kilometer (Comptroller General of the United States, 1976) depending on length of stream, sources of available data, basin configuration, and scheduling of tasks. Table 1 presents the average USACE costs per task involved in preparing a flood hazard map. The main objective of utilizing remote sensing in the mapping of floodplains would be either to reduce overall costs by assisting in the preparations of conventional products or to provide superior products at increased efficiency at similar costs.

RELATED RESEARCH

In-Situ Programs

To better understand the relationship of inundation and natural characteristics a review of related research was conducted. The research of interest was directed toward establishing patterns on the ground that indicate the historical presence and frequency of flooding. In the terminology of remote sensing technology this is referred to as "in-situ" research; namely, that research conducted on-the-spot of the actual phenomenon.

Historical techniques involve observations of high water marks and flood damage related to specific floods. Several investigators have mapped flood lines based on trash accumulation, scarred trees, and sediment deposition (Leopold and Skibitzke, 1967; Sigafoos, 1964; and, Lee, Parker, and Yanggen, 1972). Several limitations compromise the effectiveness of this technique, however. First, the flood which produced the evidence may have obliterated similar indications of earlier and less severe floods; and, second, rare floods and their high-water marks may not have been observed on the stream which one desires to map.

Several investigators have relied on geomorphological features to indicate the location and frequency of flooding (Burgess, 1967; Reckendorf, 1973; and, Wolman, 1971). The predominant feature used is the terrace, but of significant value are alluvial fans, natural levees, bars, oxbows, abandoned channels, marshes, deltas, and swales. These indicators, however, are of little more than local value and may not even be present from one watershed to the next.

Field investigators (Parsons and Herriman, 1970; McClelland, 1950; Coleman, 1963; and, Woodyer, 1966) have shown that soils are configured horizontally and vertically to reflect flooding patterns. These patterns have been mapped by agencies such as the SCS and have been used to delineate boundaries by Yanggen, Beatty, and Brovold (1966), McCormack (1971), Cain and Beatty (1968), and Viaene (1969). The difficulty in employing this approach is simply that many areas have not been mapped and that original field work on the subject is expensive and time-consuming.

Finally, vegetation has been noted by many researchers as exhibiting patterns related to flood conditions (Everitt, 1968; Wistendall, 1958; Helfley, 1937; Sollers, 1974; and Sigafoos, 1961, 1964). Various species possess tolerance to standing water or poorly-drained soils and are typically associated with the floodplain. Others require well-drained soils and are usually found in terrace locations. Broad size-groupings also are related to distance from the floodplain. The problem associated with using vegetation indicators is that, beyond fairly general relationships, distinct boundary delineation is rendered difficult due to the hardiness of vegetation species and their ability to flourish in less than optimum conditions. The result is a heterogeneous mixture that becomes difficult to interpret at close inspection. The best perspective for this approach is a distant one.

Floodplain Delineation Using Remote Sensing

Remotely sensed information from aircraft and satellites have been used to perform floodplain mapping by two complementary methods. The dynamic or actual flood method images floods as they actually occur or soon after the high waters have receded. This method takes advantage of the fact that visible evidence of inundation in the near infrared region of the spectrum remains for up to two weeks, and sometimes longer, after the flood. This evidence is in the form of significantly reduced near infrared reflectivity in the flooded areas caused by the presence of increased surface-layer soil moisture, moisture stressed vegetation, and isolated pockets of standing water. Satellite data of the type being collected by Landsat 1 and 2 provide the most pertinent spacecraft information for flood observations because of the relatively high resolution, cartographic fidelity, and the near infrared sensors onboard. Mapping of floods using Landsat photographic data have been reported by Hallberg, Hoyer, and Rango (1973), Deutsch and Ruggles (1974), and Rango and Salomonson (1974). Williamson (1974) has employed digital Landsat data for similar flood mapping. The compilation of a flood map from an actual event constitutes a floodprone map for that section of stream for a particular flood frequency. This dynamic map can be continually improved as additional floods are observed on the stream in question.

The second method, referred to as the static approach, utilizes the fact that many floodplains have been recognized with remote sensing because of permanent or long term features left as a result of historical floods. The natural and artificial indicators of the floodprone areas that can be detected with remote sensing have been enumerated by Burgess (1967). These floodprone areas also tend to have multispectral signatures that are distinctly different than the signatures of surrounding non-floodprone areas. Harker (1974) performed a multispectral analysis of digitized aircraft photography in Texas that indicated a reasonable correlation between floodprone area boundaries based on computer processed multispectral digital data and those produced by conventional techniques. Clark and Altenstadter (1974) used a combination of high altitude aircraft and satellite data to produce floodprone area maps in Arizona to meet state requirements. Rango and Anderson (1974) used Landsat exclusively to provide small-scale floodprone area maps in the Mississippi River Basin that compared favorably with existing surveys.

Flood and floodprone area observations from Landsat are indeed promising, but only on a regional basis. Most satellite photographic flood and floodplain mapping has been done at scales no larger than 1:250,000. Digital Landsat maps of floods and floodplains have been produced at 1:24,000 and 1:62,500 scales, but they do not meet national map accuracy standards. For most legal requirements, it is necessary to produce maps at even larger scales.

CENTRAL PENNSYLVANIA STUDY

Test Sites

Capitalizing on previous work to date, the USACE elected to pursue the potential of mapping floodplains based on natural indicators. The study area chosen for the research was a portion of the West Branch of the Susquehanna River in north central Pennsylvania as shown in Figure 1. The test site was selected because it exhibited a variety of land covers and physiographic densities, light industry, agriculture, and forest. Physiography is characterized by both steep and gently sloping valleys and floodplains of varying widths. The section of the West Branch of the Susquehanna River from point A to point B in Figure 1 is in the Ridge and Valley Province, where the valley is broad with a moderately wide floodplain predominantly used for agriculture. This portion of the study area will subsequently be referred to as the "agricultural and developed" area. The section of the river from point B to point C in Figure 1 is in the Allegheny Plateau Province, where the largely forested valley is steep with a narrow floodplain. This portion of the area will subsequently be referred to as the "forested" area.

The study area has a humid continental climate (U.S. Department of Agriculture, 1966), with warm summers and long cold winters. The average annual temperature is 10.7° C, with January and July mean temperatures of -14° C and 23.1° C, respectively. The average annual precipitation is about 102 cm, which includes an average total seasonal snowfall depth of 94 cm.

Data Sources

Ground data. The Flood Plain Information report (U.S. Army Corps of Engineers, 1973) prepared for the West Branch of the Susquehanna River was used to obtain the floodplain limits established on the basis of engineering parameters for comparison with those limits established using remotely sensed data. Maps at a scale of 1:24,000 of the West Branch of the Susquehanna River showing the extent of the 100-year return period flood as well as the extent of flood waters during Hurricane Agnes in 1972 were provided by the USACE.

Among other sources of information available for the study area were the USGS 7.5 minute quadrangle topographic sheets. The Soil Survey of Clinton County, Pennsylvania (U.S. Department of Agriculture, 1966), as well as the SCS worksheets for the Lycoming County Soil Survey (in progress) were used for soils information throughout this investigation. Various geologic maps and reports were also consulted (Stose and Ljungstedt, 1932; Flint, 1947; MacClintock and Apfel, 1944; and Peltier, 1949).

An extensive field analysis of the entire test region was conducted in July 1973. For several days, a team of Pennsylvania State University and USACE researchers inspected the test site river banks and terraces to determine vegetation species type and composition, bare soil texture, and drainage of the floodplain to facilitate the calculation of spectral signatures.

Aircraft data. The NC130B aircraft of NASA flew the test area at altitudes of approximately 1525 meters (5000 feet) and 4575 meters (15,000 feet) in April and June, 1973. Color positive and color infrared photography was taken, along with data from 14 channels of the Bendix 24-channel multispectral scanner.

A multispectral scanner (MSS) is an optical-mechanical scanning device used to detect levels of electromagnetic energy emanating from the earth's surface in many discrete wavelength intervals (channels). Through the use of a rotating mirror, the area beneath the aircraft is scanned in successive contiguous lines in a direction perpendicular to the flight of the aircraft. The energy received from the earth's surface is reflected by the mirror through a series of lenses and prisms which refract the energy into components of selected wavelengths onto an array of detectors. Each detector then produces an electrical output signal proportional to the energy received. These signals can then be used to modulate a light source to expose photographic film, or they can be recorded on magnetic tapes for later analysis.

The channels and their corresponding wavelength intervals for the Bendix 24-channel MSS are shown in Table 2. However, only channels 1-11, 13, 15, 23, and 24 were operative, and in some areas only channels 4, 5, 6, 8, 9, 10, 13, and 15 were digitized due to data volume limitations. At the 1525 meter altitude, the size of a ground resolution element (or pixel) of the 24-channel MSS is approximately 3 meters on a side, depending on minor aircraft altitude and velocity variations. At the 4575 meter altitude, the size of a ground resolution element or pixel is approximately 9 meters on a side. NASA provided the computer compatible tapes, containing the uncalibrated digitized MSS data, as well as imagery of selected channels.

Satellite data. Since launch of Landsat, most observations have been taken by the MSS in the visible and near infrared wavelengths. The four MSS channels (discrete wavelength intervals) cover the 0.5-0.6, 0.6-0.7, 0.7-0.8 and 0.8-1.1 μm portions of the electromagnetic spectrum. The resolution of the Landsat MSS is approximately 80 m. Features smaller than 80 m may sometimes be detected, however, because of favorable geometric and contrast characteristics of a given object on the earth's surface.

In the agricultural and developed portion of the study area (from point A to point B, Figure 1), data from the 16 May and 25 October 1973 scenes (identification numbers 1397-15245 and 1459-15221, respectively) were selected for analysis. These scenes were selected to obtain the maximum area of exposed bare soil. Data from the 6 September 1972 scene (identification number 1045-15240) were selected for analysis of the forested portion of the study area (from point B to point C, Figure 1). This scene was selected for maximum expression of tree foilage. All Landsat MSS data were supplied by NASA in the form of computer compatible tapes as well as imagery of selected channels.

Approach

The Penn State ORSER system for analyzing multispectral scanner data is based on multivariate statistical techniques. Each observation, identifiable by scan line and element number, consists of a vector composed of multispectral scanner response values with as many components as there are channels. The programs used in this study are all operational and are documented at the user level (Borden, et al., 1975).

The first step is to select the particular targets and areas of interest and the computer tapes corresponding to these areas. A subset of data is then produced for the specific area of interest. The following step is to produce a brightness map employing all available channels which can be used for verifying general location and zooming in on specific targets. No previous knowledge of target spectral signatures is required for the brightness map.

Subsequently, a program is employed to identify areas of local spectral uniformity based on variation between spectral signatures of near neighbors as "the measure of similarity." The output shows the pattern of uniformity and contrasts from which the user can designate coordinates of training areas for input to supervised classifying routines. Multivariate statistics of signatures are then calculated for the training areas. Using these statistics, supervised classification and mapping can be done for the entire study area. The output is a digital character map with each category of classification represented by a unique symbol assigned by the user. Unsupervised classification or clustering options may have to be employed in combination with supervised classification to effectively classify small area or linear features, such as streams.

The ORSER system then has the capability to perform a geometric correction on a character map to rectify simple distortions resulting from sensor, satellite, and earth effects. Such geometrically corrected classification maps can be overlaid on other maps of the same scale, such as 1:24,000 scale topographic maps. This scaling feature facilitates the comparison of MSS (aircraft or Landsat) classification results with available ground truth.

Once classification of land cover had been accomplished a number of interpreters attempted to use the classified results to determine which classes were indicative of floodprone areas. In the agricultural and developed region, bare floodplain soils were used as the key feature for drawing the floodprone area boundary line. In the forested area, different vegetation classifications were related to the floodprone areas. Attempts to draw in the floodprone area boundaries were made using classified data only and then with the addition of ancillary data such as topographic maps.

Results

Floodplain classification using digital aircraft data. Several test sites were selected along the study area to test the applicability of digital aircraft data to floodplain mapping. The two major categories of interest were agricultural areas, especially those with bare soils, and forested areas. Initial individual test site selection was based on various physical characteristics of the areas, such as vegetation, topography, and (in the case of forested test sites) freedom from alterations due to the activities of man (such as housing developments) within the recent past.

The results from computer analysis of the digital MSS data in agricultural areas distinguished between floodplain and non-floodplain areas in small isolated portions of the test sites. In addition, the computer classification within one test site separated an area of moderately well-drained soil from the surrounding well-drained soils. Comparison with SCS data for this area indicated the moderately well-drained soil to be less extensive than shown on the computer output, but field inspection supported the results of the digital classification. In general, the results from computer analysis of the digital MSS data in agricultural areas were not sufficiently conclusive to delineate a continuous floodplain line. The presence of extensive bare soils in the agricultural and developed area made the April data more useful than the June data in detecting soil differences.

Results using the MSS data from the 1525 meter June flight indicate that classification differences in the forested area can be related not only to species differences, but also to differences in crown closure or canopy density within a forested area. These density differences may be a result of species composition, site quality, or a cultural practice. Local topography and the aspect of the test sites also contributed to classification differences unrelated to the natural vegetation. A comparison of the classification results of each of the available data sources (i.e., the April and June flights at both 1525 and 4575 meter altitude) showed the MSS data collected during June to be more effective than the April data owing to greater vegetative cover existing in June. Classification differences obtained using the April data were additionally ambiguous because of extensive shadow patterns which were prevalent over much of the study area at the time of this particular flight. The June MSS data at an altitude of 1525 meters were the only data which, when used for classification, were useful in delineating an area related to the floodplain.

Floodplain classification using digital Landsat data. Preliminary analysis of the 16 May and 25 October 1973 LANDSAT scenes indicated both to be potentially good data sets for the purposes of differentiating floodplain bare soils from non-floodplain bare soils. Previous research has shown that by merging tapes from two different seasons it is often possible to improve the classification of certain targets, such as hardwoods and conifers (using data merged from summer and early winter scenes). Therefore, the two scenes were merged and treated as an 8-channel data set on this basis. Merged tapes can be used in any of the ORSER programs, using the same analytical procedures employed for a four-channel subset tape.

The results of computer analysis of 8 channels of Landsat MSS data merged from two scenes were sufficiently conclusive to delineate a continuous floodplain boundary in the agricultural and developed area, which was then quantitatively compared to the USACE 100-year return period floodplain boundary. The basis for the distinction between the boundaries of the floodplain and non-floodplain areas was spectral differences in the bare soils of the two areas, which could be differentiated using the available computer routines.

Four individuals independently interpreted the resulting classification map. Each interpreter first delineated a floodplain solely on the basis of the classification map and then was allowed to consult the corresponding USGS 7.5 minute quadrangle topographic maps to refine the interpretation. Each interpreter's floodplain delineation was then compared to the USACE 100-year return period floodplain boundary in two ways: (1) on the basis of total area measured to be floodprone, and (2) by calculation of the correlation coefficient between the pairs of measured distances from the center line of the river to the two floodplain lines on both sides of the river. For this second comparison a total of 100 pairs of measurements were made.

Table 3 shows the results of the two methods of comparison for each of the four interpreters. The area of the USACE 100-year return period floodplain plus river is 4200 ha (10,371 acres). Using only the computer classification map, the results range from a 13.7% (574 ha) underestimation of the USACE floodplain to a 4.4% (184 ha) overestimation. Additional comparisons made using information on the USGS 7.5 minute quadrangle sheets improved the underestimation percentages to 7.7% (324 ha), however, the overestimation was increased to 8.8% (369 ha).

Correlation coefficients representing the "nearness of fit" of the computer classification map and the USACE 100-year floodplain aided by information gleaned from USGS maps were calculated for each interpreter. These coefficients ranged from 0.87 to 0.92 (Table 3), indicating a rather close association of the two floodplain delineations. A scattergram illustrating the relationship between the two floodplain delineations, using one interpreter's results, is shown in Figure 2. In this case, the horizontal differences between the two floodplain delineations ranged from 0 to 74 meters with a mean-difference of 13 meters.

A substantial lack of correlation between the USACE floodplain limit and the floodplain delineation based on the computer classification map existed in two situations. In the first case, small isolated areas in the floodplain having vegetated or developed land cover were not recognized in the computer classification as floodplain. This was not totally unexpected since the classification map was developed primarily on the basis of differentiating floodplain from non-floodplain bare soils. Interpretitive skills played an important role in overcoming the lack of information in these relatively small areas.

The second situation in which a discrepancy appeared between the two lines occurred where the computer classification identified "floodplain" areas based on the presence of bare soils while the USACE considered them outside of the floodplain. The elevation of these areas is only slightly higher than the adjacent floodplain area and could be remnants of old river terraces. Field inspection revealed a strong possibility that inundation by flooding waters could occur since the meander of the river channel would allow flood waters to flow in the direction of the areas in question. Based on the results of this field inspection, the three cross-sectional observations in this area were not included in the calculation of the range and mean but were included in the calculation of the correlation coefficients.

As opposed to the 8-channel data set used in the agricultural and developed area analysis, the delineation of the floodprone area in the forested region of the study area was based on classification results from a set of spectral signatures developed from only three channels of Landsat-1 data on a single date using the unsupervised classification approach. The resultant nine signatures categorized as floodprone do not correlate with individual floodplain features, such as floodplain bare soil or floodplain vegetation, but represent a variety of physical features associated with the floodplain in this area.

The separation of open and developed areas from forested areas accounts for a major portion of the floodplain classification. Generally, these open areas are wide and flat terraces adjacent to the river and are the only sites suitable for agricultural or residential development. In several instances upland open areas were incorrectly classified as floodplain. These areas can be readily identified as non-floodplain because of their position relative to areas classified as river and because their shape suggests a feature other than a floodplain. This discrepancy was easily accounted for during interpretation of the classified data.

An attempt at improving the delineation of a floodprone area boundary in forested areas on the classification map was made by three interpreters in the same fashion as performed in the agricultural areas. In all cases the interpreted floodplain area overestimated the USACE floodplain area ranging from 751 ha (38%) to 1427 ha (72%). This overestimation, however, may indicate that the interpreted line identifies a boundary that represents a higher flooding frequency than the 100-year flood. The correlation coefficients between the USACE floodprone boundaries and the interpreted boundaries (0.29-0.35) in the forested sites were much lower than for the agricultural areas. There is a strong correlation, however, between each of the interpreted boundaries (0.82-0.90), indicating a high degree of repeatability. On several sites where the interpreted line grossly overestimated the USACE 100-year flood line, inspection of aerial photos revealed close proximity of mountain streams that would affect and enlarge the previously mapped floodplain. In general, however, floodplain delineation in the agricultural and developed areas was much easier than similar delineation in forested areas.

Discussion

Aircraft. A continuous floodplain line could not be delineated on the basis of computer analysis of the aircraft collected MSS data. However, the computer analysis did indicate a break between floodplain and non-floodplain within small areas which correlated with one or more floodplain limits derived from USACE maps, soils data, and USGS sources.

The inability to consistently map a floodplain boundary using aircraft data based on natural indicators was due to several factors regarding the data collection medium and the study area. The study area selected for this analysis has a very complex topography and many land cover types. The slopes range from nearly level to quite steep, with greatly varying aspects. The land cover types include urban and residential areas, small agricultural fields, and heterogeneous forest stands. Research in study sites exhibiting greater uniformity has yielded considerably more successful results. The impact of variable terrain and land use on pattern recognition is profound.

No attempt was made at a sensitivity analysis or spectral band selection to discern only those natural features that are strongly associated with flood frequency. The decision was made to proceed with a multispectral analysis since this approach was the strength of the ORSER software. There may well be, however, features in nature that are more easily identified by selective band processing and this approach should be conducted in any follow-on investigation, especially if similar terrain is selected.

The method and type of aircraft digital data collection system were also factors affecting the potential for successful findings in this portion of the investigation. The data volume alone yielded enormous bits of information that had to be arrayed, formatted, screened, catalogued, and analyzed. In this regard the satellite techniques are preferable in that significantly less data are required to cover the same size area. The aircraft platform, being subject to variable atmospheric buttressing, will occasionally render irregular land parcel data. This phenomenon has a serious impact on the transferability of signatures derived in one location to another. In addition, the platform, because of the narrow field of view afforded, needs to be directed precisely over the target to obtain radiometrically accurate results. In many cases during this study, continuation of analysis along a floodplain segment was aborted due to lack of coverage. This problem would have been obviated by using shorter flight lines to accomodate stream meander patterns.

The supplemental, high quality, aerial photography collected for this study was extremely useful as a source of ground truth to which computer classification results of the digital MSS data could be easily compared. It was also used to identify areas which required more intensive on-site investigation.

<u>Satellite.</u> As opposed to the discontinuous, aircraft derived floodplain boundary, satellite data afforded a continuous boundary that could be statistically compared to a boundary based on engineering parameters. The comparison revealed strong agreement in the agricultural and developed sites and indicated a marked overestimation in forested sites. The discrepancy between the two areas

may be due in part to the fact that two scenes of four channels each were merged and used as an eight channel set in the agricultural and developed study area, whereas data from a single scene consisting of only three good quality channels were used in the forested study area. Thus greater differentiation potential existed for the agricultural and developed study area. Additionally, although the remote sensing floodplain boundary in the agricultural and developed area corresponded closely to the USACE 100-year return period boundary, it is possible that the remote sensing boundary identified in the forested area was an indicator of the limit of a flood with a return period greater than 100 years.

It appears that Landsat digital MSS data is superior to low altitude aircraft-collected digital MSS data for floodplain mapping. However, this should not be taken as a recommendation of an optimum altitude for data collection, but only as a comparison of data from the two altitude ranges available. Based on past experience with high altitude aircraft imagery, it is possible that MSS data from such a platform would be directly amenable to floodplain identification and mapping.

SUMMARY AND CONCLUSIONS

The central Pennsylvania study differed from most of the previously mentioned floodprone area studies in that the approach primarily employed multispectral classification techniques using digital MSS aircraft and satellite data.

This approach not only makes maximum use of the resolution capabilities of the sensor systems but also contributes to objective interpretation of the floodprone areas. The analysis of these floodprone areas is not fully automatic, however, but requires the attention of an expert in remote sensing who is familar with floodplain areas to allow for the final interpretation and location of the floodprone boundary. The Pennsylvania State ORSER digital approach permitted Landsat results to be displayed at a convenient 1:24,000 scale and aircraft data at even larger scales.

As in the central Pennsylvania study, Harker (1974) in Texas used maximum likelihood techniques for classification of the floodplain data. In his study, however, aircraft multispectral scanner data had to be simulated. Harker (1974) found a good correlation between the remote sensing-derived boundaries and the USACE 100-year flood boundaries, in fact, better than in the central Pennsylvania study. His study area only covered about 2.5 km^2, however, and results from the central Pennsylvania study in similar small areas were as conclusive in locating the floodprone area boundary. In addition to the size of the site, topography and land use in Harker's (1974) area were much more uniform than in central Pennsylvania. In the case study, it appeared that the high resolution of the low altitude aircraft survey detracted from the identification of the floodprone area boundary. The small pixel size of aircraft data resulted in an overabundance of detail which camouflaged the detection of the subtle floodplain boundaries in many areas. In contrast, the lower resolution of the Landsat MSS data seemed more effective in delimiting floodplain boundaries on complex areas because the larger pixel size integrated over a number of specific features to come up with a single radiance value. When compared to other radiance values, the satellite-derived floodprone area boundaries tend to stand out more predominantly than they do in the low altitude aircraft data.

Rango and Anderson (1974) employed photointerpretation to derive their Landsat floodplain boundaries study along the Mississippi River. Their comparison of the total floodprone area derived from Landsat with the same area as delineated on USGS floodprone area maps were similar to the results from the agricultural and developed areas from the central Pennsylvania study. Comparisons between the horizontal difference of the two boundaries, however, reveals that the results from the central Pennsylvania study are markedly superior. This undoubtedly results from the use of digital data which produces the maximum resolution obtainable during interpretation of the various floodplain features.

Based on the results from remote sensing floodplain studies, including the central Pennsylvania study, several comments on the general suitability of using remote sensing data in floodplain management can be made. Digital multispectral scanner data and automatic digital analysis combined with a certain amount of user interpretation is to be preferred over conventional photointerpretation. It appears that remote sensing analysis can delineate floodprone areas best in agricultural and limited development areas as opposed to areas covered by a heavy forest cover. Visible and near infrared channels are necessary for analysis.

The digital data analysis can produce flood hazard boundary maps at a useable scale for rural areas, namely, 1:24,000. Similar maps at scales useful to urban areas must await improved resolution MSS data from space or from high altitude aircraft data. Even if the maps are at the appropriate scales, it is unlikely that floodplain management agencies will immediately adopt this new procedure. Rather, it is more likely that the remote sensing technique would be used as a form of preliminary planning information or as an internal check on previous or ongoing floodplain studies. Remote sensing would be used as another form of local knowledge and could be important in identifying areas where major discrepancies in the conventional map may exist and further surveys are merited.

Once a survey has been completed, whether it be conventional or remote sensing based, the remote sensing data can provide detailed land use analysis in floodprone areas that can serve as a base for assessment of potential flood damage. The enforcement phase of the National Flood Insurance Program has received little attention to date because of severe FIA manpower limitations (Comptroller General of the United States, 1976). The Comptroller General report recommends in addition to improving community involvement in the enforcement of flood plain management regulations, that FIA "provide a means of systematically spot checking community compliance with program requirements". It is quite conceivable that remote sensing can assist in effectively monitoring floodplain activities. Even at Landsat resolution, major and minor land use changes in floodplain areas can be detected. Such an enforcement system would permit a check on reporting of the local communities in the program.

The continued acquisition of remote sensing data over the United States will serve to record actual flooding events on an increasing number of streams. Such data will increase the availability of actually observed flooded area maps and up-date flood hazard boundary maps where they already exist. Continued remote sensing research in floodplain management should concentrate on attaining the optimum resolution with multispectral sensors, whether from high altitude air-craft or space platform. Finally, as the enforcement phase of the National Flood Insurance Program receives increasing emphasis, the capabilities of remote sensing should receive serious consideration as an integral part of the program.

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Table 1

Average Costs Associated with Specific Tasks in Mapping Flood Hazard Areas*

Task	Cost
Reconnaissance of Site	$300/km
Aerial Surveys	$500/km
Hydrology	$190/km
Hydraulics	$250/km
Profile Concurrence	$1,000/study
Land Surveys	$200-225/cross section
Coordination	$1,500/study
Travel	$2,000/study
Map Preparation	$5,000/study
Report	$2,500/study

Total cost to survey and prepare report for 32 km reach is $72,000 or $2,250/km. This assumes 16 km of detailed survey work with 6 cross sections per km.

*Based on average costs to complete each task as calculated for previous studies by USACE, January 1976.

Table 2

Bendix 24-Channel MSS Spectral Intervals

Channel	Spectral Band (micrometers)	Channel	Spectral Band (micrometers)
1	0.38 - 0.40	13	2.10 - 2.38
2	0.41 - 0.45	14	3.65 - 4.00
3	0.46 - 0.52	15	4.49 - 4.75
4	0.54 - 0.58	16	6.30 - 7.50
5	0.59 - 0.64	17	8.50 - 8.90
6	0.65 - 0.69	18	9.[illegible] - 9.50
7	0.71 - 0.76	19	9.50 - 10.20
8	0.77 - 0.81	20	10.20 - 11.00
9	0.83 - 0.88	21	11.20 - 11.90
10	0.98 - 1.04	22	12.20 - 13.00
11	1.20 - 1.30	23	1.14 - 1.16
12	1.53 - 1.63	24	1.05 - 1.09

Table 3

Floodplain Boundary Comparisons for the Agricultural and Developed Portion of the Study Area

Interpreter	Area Comparisons (per cent)[1]		Correlation Coefficients[2]	
	Without Aid of Topographic Maps	With Aid of Topographic Maps	Without Aid of Topographic Maps	With Aid of Topographic Maps
1	-8.6	-0.4	0.85	0.92
2	+4.4	+8.8	0.86	0.92
3	-2.2	-0.8	0.86	0.90
4	-13.7	-7.7	0.83	0.87

[1] The total area of the floodplain and river within the 100-year return period floodplain determined by the U.S. Army Corps of Engineers was 4200 hectares (10,371 acres). A positive value here indicates an overestimation and negative value an underestimation.

[2] Based on 100 observations with all correlation coefficients highly significant.

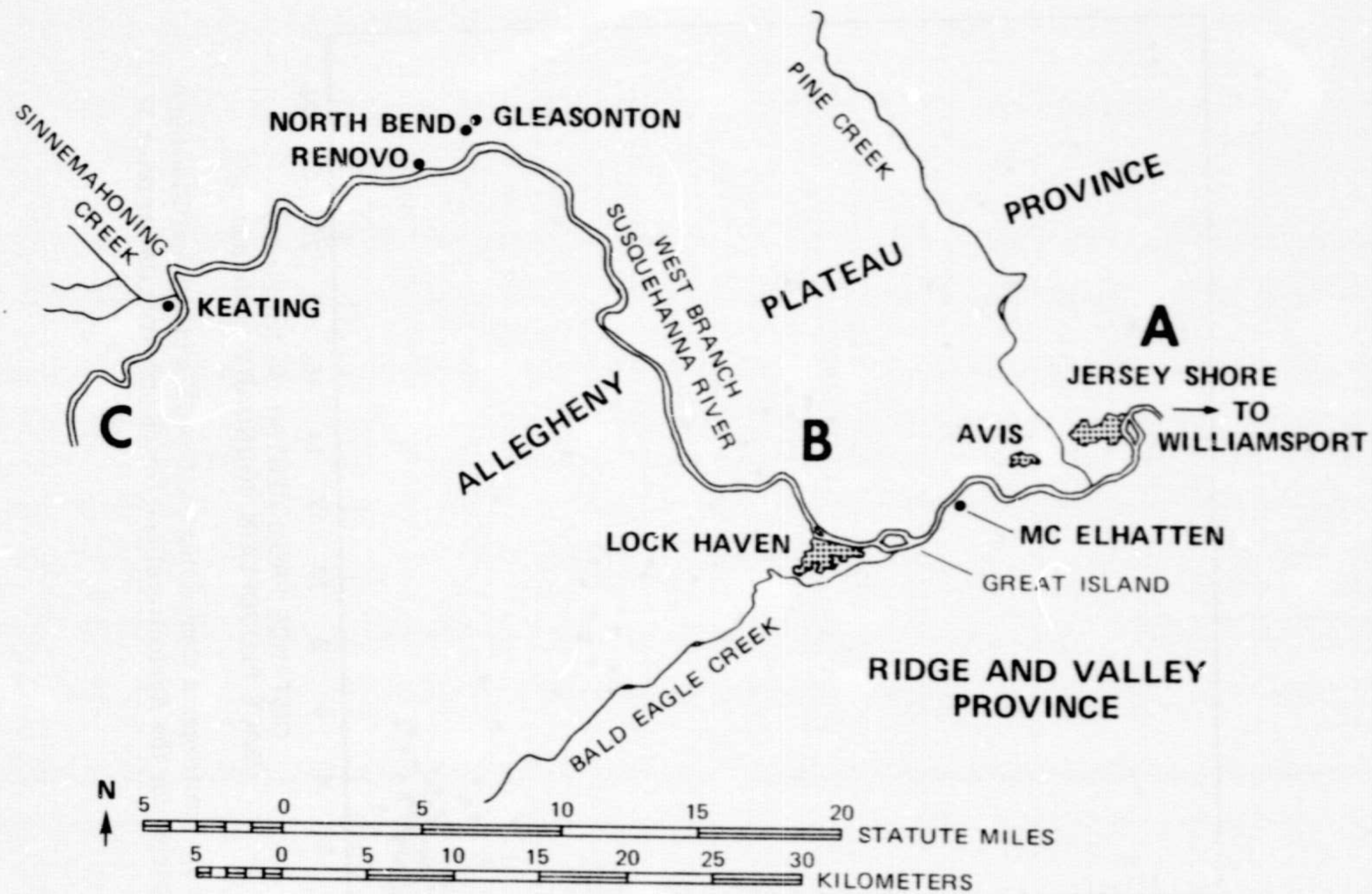

Figure 1. Central Pennsylvania Study Site Along the West Branch of the Susquehanna River

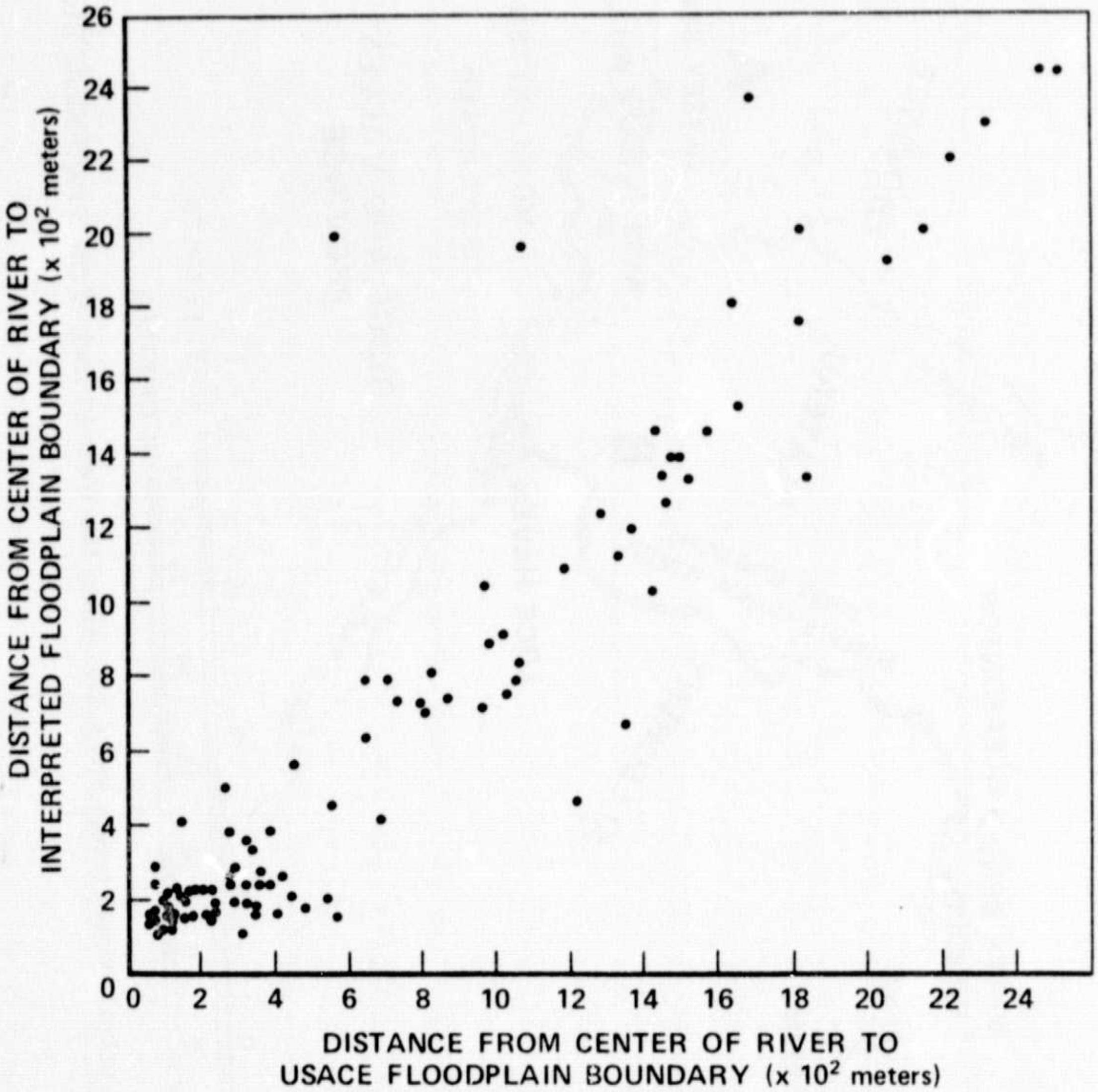

Figure 2. Scattergram Comparing the USACE and Landsat Floodplain Boundaries for the Agricultural and Developed Area (Interpreter 1)